CLASSIFICATION OF STORMWATER TREATMENT DEVICES FOR PERFORMANCE EVALUATION

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Abstract: A large number of stormwater treatment devices are commercially available to meet the need of urban areas. Substantial differences are evident in the way the performance of these treatment systems are evaluated and presented. Various measures to indicate treatment performance are in use and this makes comparisons between different systems difficult. Classification of treatment systems based on performance curves can assist in evaluating treatment systems on a more consistent basis. We focus on physical treatment systems that have robust capabilities to handle high and variable flow rates and are especially suitable for suspended solids removal to achieve non-potable water quality. This paper presents a new classification scheme based on the principal treatment mechanism for screening of treatment system.

Key words: Stormwater treatment devices, classification, suspended solids.

1 INTRODUCTION

The world is urbanizing rapidly. At present around 60% of the world's population live in urban areas and worldwide it is estimated that by 2025 more than 90% of the population growth will take place in urban areas (Ujang & Henze, 2006). As urban population increases, the surrounding rural areas will also quickly develop. Finding ways to satisfy water demand will become one of the major challenges in these areas. Most large cities are already facing water supply problems and these will continue to increase in the future.

The situation is no better in Australia. It is the driest inhabited continent on earth, with water restrictions commonplace in most major cities. With a growing population there is ever increasing pressures on water supply. Reuse of stormwater could be one of the important and sustainable management strategies to address the water crisis especially when water is not required to be of drinking water quality.

Common uses of harvested stormwater include the irrigation of parks, ovals and golf courses and other municipal and commercial purposes (National Water Quality Management Strategy [NWQMS], 2009). It is a cost saving as the non-potable stormwater can replace potable water used for irrigation. This can contribute to the greening of urban areas ultimately leading to enhanced wellbeing of the environment and people (Mitchell et al., 2007, Argue & Pezzaniti, 1999).

Stormwater harvesting and reuse complements the sustainable management of urban water. However, stormwater harvesting is not as simple as directing stormwater drains into a dam. It consists of collection, treatment, storage and use of stormwater run-off from urban areas (Huber, Strecker, Heaney, & Weinstein, 2009). Providing space for storage and treatment could be a major challenge in urban areas. In addition, stormwater runoff conveys all kinds of pollutants from roads, driveways and footpaths which can be divided into 3 categories (Water Environment Research Foundation [WERF], 2006, Environment Protection Authority [EPA], n.d.):

- ➢ natural-organic material (e.g. leaves, grass clippings and sediment);
- ➢ chemicals (e.g. detergents, coolant, oil, grease, fertiliser and paint); and
- ➢ litter (e.g. plastic bags and cigarette butts).

A competitive commercial market has recently appeared to address the challenge of urban stormwater quality management, where land cost is high and availability of space is low. Approaches include catchment basin inserts, constructed wetlands, tanks and bioretention cells, in addition hydrodynamic separation or filtration within underground vaults (Fassman, 2006). Catchment basin insert, hydrodynamic separator, tanks etc are underground devices designed to remove floatable debris and suspended solids from stormwater runoff by sedimentation. A challenge is to group them logically as their performance is not evaluated on a consistent basis, which led to variation in their claim. A summary of the commercially available stormwater treatment devices and their performance have been published by the Victorian Stormwater Committee (1999) and the California Department of Transportation ([Caltrans], 2004).

Treatment System Components (TSCs), a term used by Quigley (2005) for various stormwater treatment devices, is adopted in this paper. The objective of the study is to categorize commercially available TSCs that are particularly suitable for urban areas and capable to remove suspended solids up to a non-potable reuse standard.

As more and more manufacturer stormwater treatment devices enter the market, the selection of treatment system on a consistent basis gets more confusing. Stormwater managers are searching for effective, consistent and rapid methods for evaluating device performance to assist proper TSC selection. Identifying the correct category where the system belongs based on their principal treatment mechanism could be an important first step.

Percentage removal of suspended solids is used as the most common parameter to assess the performance of TSC and it is expressed as Total Suspended Solids (TSS). TSS is commonly utilised as suspended solids is the primary parameter of interest for most regulatory agencies, and is it easiest parameter to simulate Clark & Pitt (2008). Strecker et al. (2004) argued that using percentage removal as an indicator of efficiency often gives inaccurate results. Recently the International Stormwater Best Management Practice (BMP) Database ([ISBMPD], 2007) eliminated percent removal as a way to assess treatment performance and some of the reasons behind are: Percentage removal is primarily a function of influent water quality. In most of the cases, higher influent pollution concentration leads in reporting higher pollution removal by TSCs. TSCs with higher removal (e.g. >80% removal of TSS) may have unacceptable high concentration of pollutants (e.g. > 100mg/L TSS). Methods for calculating percentage removal are inconsistent. The standard reporting of percentage removal carries no statistical support. It does not adequately reflect the effect of volume reduction etc. (ISBMPD, 2007). As an alternative, we consider particle count to be a suitable parameter. Particle count is simply the number of particles of a given size fraction per volume of aqueous suspension. It is a two-dimensional measurement of particle numbers and size, therefore it can produce accurate and precise information on water quality, system performance and treatment efficiencies compared to TSS and turbidity measurement methods Kavanaugh et al. (1980) and Moritz and Hoffman (1994). Particle counting can be carried out using direct methods (e.g. microscope) or using automatic particle counters based on light scattering, light obscuration and electrical resistance. This study seeks to categorize TSCs in a logical way based on their dominant or most recognizable mechanism of pollutant (suspended solids) removal. In a second stage, rearrangement of TSCs on the basis of performance curves developed using log reduction particle count will be carried out.

2 EXISTING CLASSIFICATION SCHEMES

Generally water treatment systems have been grouped on the basis of treatment mechanism, level of treatments or target pollutants removal etc. In the case of stormwater, few studies were found in the engineering literature on the classification of stormwater treatment systems.

Quigley (2005) classified TSCs based on Unit Process and Operations (UOPs); the term UOPs, commonly used in the stormwater treatment, is borrowed from wastewater treatment research, where the term "process" implies biological and chemical processes and "operation" implies physical process. The same concept has been applied in stormwater treatment (WERF, 2005). According to Minton (2007), a problem with this definition is that not all physical processes can be categorised as a physical operation due to their chemical dependency. Minton (2007) proposed a new classification with agreement on a common family for the similar treatment system to which design criteria are comparable. Terms like unit process and unit operation were used but defined differently. Unit process meant the mechanism of pollutants removal, and unit operation is referred to a treatment in which one or more unit process occurs. The Minton scheme has five different families, namely Basins, Swales, Filters, Infiltrator and Screens. Systems with common key characteristic are grouped as families. The classification is done from a designer perspective. The classification proposed in this paper is to assist the better selection of treatment system on a consistent performance basis.

3 PROPOSED CLASSIFICATION SCHEME

As a starting point, treatment systems with common characteristic are grouped into two broad categories based on treatment mechanism, namely Density Separation and Size Separation, these are the first level of categorization (Level I, Tab. 01). Density separation is a physical process, in which gravity removes settleable solids and associated pollutants, floatables, and dispersed petroleum products. Settling velocities of particles is the fundamental engineering principle of gravity separation (Minton, 2005). In size separation, suspended solid are separated by interposing a medium where oversize solids in the fluid are retained depending upon the size of media pores and its thickness. These treatment mechanisms are selected keeping in mind the types of performance curve required to present the particle removal performance of TSCs. As shown in Fig. 01, a hierarchy of up to five levels (referred to as Levels I to V) is proposed to classify TSCs.

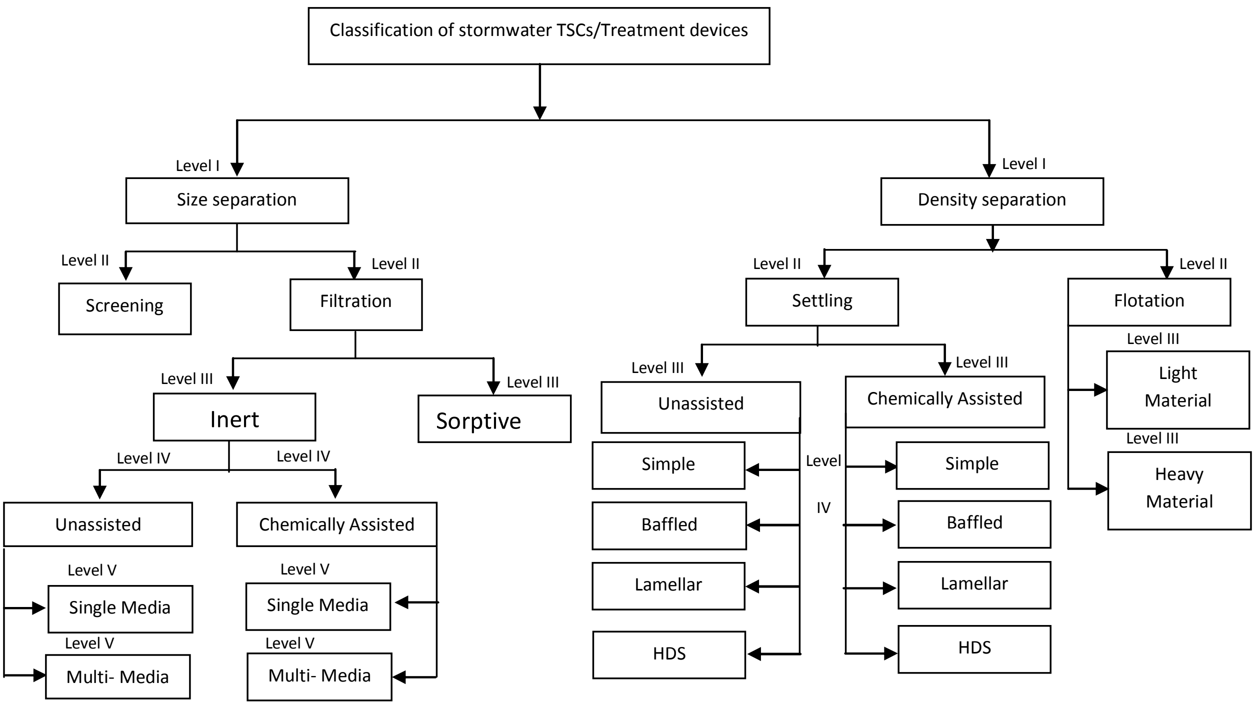

FIGURE 01: Proposed Classification for TSCs.

Past evaluations of stormwater treatment to a re-use standard suggest that high rate physical processes are more effective than biological processes in many situations (Fan, Field & Connor, 2000). Nearly all treatment systems employed today to remove pollutants of concern from stormwater runoff rely on a physical removal process (Kayhanian, Young & Stenstrom, 2005). Physical treatments have robust capabilities to handle high and variable flow rates. Treatment mechanisms also include biological processes and hydrological operations. Biological processes include nutrient assimilation, uptake and storage, and microbial mediated transformations. These processes are generally more relevant to the treatment of wastewater with high nutrient and organic load, particularly municipal sewage. Biological processes are more vulnerable to flow variation, and to the high concentration of non-biological solids in stormwater. Hydrological operations are for flow attenuation and volume reduction. Therefore biological process and hydrological operations are not discuses in the paper. Treatment mechanisms covering Levels I and II of the classification scheme that are mainly relevant to urban stormwater are listed in Tab. 01.

Chemical processes like flocculation/precipitation is also categories either under size separation or density separation as these are the ultimate method for the removal of particulate pollutants.

An individual treatment system may have more than one treatment mechanism (e.g. chemically assisted settling commonly used in water treatment utilizes coagulation, flocculation and settling), so classifying a TSC may not always be definitive. In such a case, the TSC is grouped according to its dominant or most recognizable treatment mechanism.

TABLE 01: Proposed Level I & II Classification for Stormwater TSCs

StormwaterTreatment Mechanism		
Level I	Size Separation	Density Separation
Level II	Screening	Settling
	Filtration	Flotation

3.1 **Size separation**

Screening and Filtration are the Level II subcategories of Size Separation.

3.1.1 Screening

Screening is used for removing large objects such as litter, rocks and vegetative debris. Numerous screening devices are available commercially. Screening can often be an effective preliminary treatment for stormwater to remove coarse material at the early stages of the treatment cycle by placing obstacles such as screens, racks, and inlet gates in the flow path that only allow the passage of particles that are smaller than the gaps in the obstacles. Ignoring initial screening may negatively affect the performance of other TSCs, reduce the longevity of these treatment devices, and increase maintenance frequency.

3.1.2 Filtration

Filtration is the process of removing suspended solids from water by passing the water through a porous media, generally to remove fine suspended particles. Filters are designed to remove particulate matter either on the surface of the filter or within the pore space of the filter.

The combination of grain size and bed depth determines the effectiveness of the filter (Naghavi & Malone, 1986, Tobiason, Johnson, Westrehoff, & Vigneswaran, 1993). Sansalone, Koran, Buchberger and Smithson (1998) observed that when the ratio of media diameter to particle diameter is less than 10, particles are usually removed by surficial straining. When this ratio is between 10 and 20, particles tend to undergo filtration within the pore volume, and this ratio range generally contributes to a loss of filtration capacity of the treatment system if appropriate maintenance measures are not undertaken (Sansalone et al., 1998). Finally, with ratios greater than 20, little void space is filled by the particles and sedimentation and filtration tend to become the dominant removal processes.

Filtration is further divided into Inert and Sorptive depending on the type of media used (Level III, Tab. 02). Inert media such as sand basically physically removes particulate pollutants. On the other hand, sorptive media filter removes dissolved pollutants.

Inert Media filtration is either chemically assisted or unassisted (Level IV, Tab. 02). The distinction is based upon chemical pre-treatment of the water to be treated. In unassisted filtration, the size of particulate pollutants is not changed by pre-treatment whereas in chemically assisted filtration, filtration is carried out after chemical treatment. This can be direct or contact filtration. In contact filtration, water is applied to the filter without chemical addition or with chemical addition but without separate flocculation. Direct filtration has chemical flocculation but not sedimentation.

Inert media filter can be characterized as single media and multi -media (Minton, 2005), depending on the number of filter elements in the treatment system (Level V, Tab. 02).

Sorption media filtration removes dissolved constituents by attachment to filter media at the molecular level (Minton, 2005). Since it is not concerned with removal of suspended solids, it will not be discussed in this classification.

TABLE 02: Classification of Filtration

Level II	**Filtration**	
Level III	Inert media	Sorptive Media
Level IV	Chemically Assisted	
	Unassisted	
Level V	Single Media	
	Multi Media	

3.2 **Density separation**

Density separation refers to the separation mechanism in which pollutants are separated by sedimentation and flotation (Level II, Tab. 03). Sedimentation is the gravitational settling of particles having a density greater than water (Huber et al., 2009).

3.2.1 Settling

Settling is classified into chemically assisted and unassisted settling (Level III, Tab. 03) depending upon chemical treatment prior to settling. Both chemically assisted and unassisted settling is further classified into simple settling, baffled settling, lamellar settling and hydrodynamic separation or HDS (Level IV, Tab. 03).

In simple settling, stormwater is introduced into a large quiescent basin for a sufficient period of time so that the majority of the particles in the water settle to the bottom of the basin. Settling times, ranging from 24 to 48 hours, are provided in urban stormwater ponds, and the resulting removal of suspended solids and associate pollutants are fairly high (Schueler, 1987). To achieve these settling time large storage areas are required. Lower removal rates of suspended solids will occur if available space is limited. Short duration settling in conventional clarifiers (HLR= 6 to 60 min) produce TSS removals typically ranging from 5 to 43% (Wood et al., 2004).

Large settling basins are not always appropriate for urban areas. Alternatively, sedimentation basins can be modified to accelerate the separation process. It can be achieved by increasing particle size, decreasing distance a particle must fall prior to removal, promoting less turbulence or introducing hydrodynamic separation. These modifications in settling basin enhance settling, reducing the basin size or increase the overflow rate that achieves the same or better quality.

Particle size can be increased by coagulation and flocculation prior to sedimentation. Addition of parallel plates or tubes in the sedimentation basin permits solids to reach a surface after a short settling distance. This is referred to as Lamellar Settling.

Baffles are flow control devices, installed within the clarifier. They are designed to modify flow patterns or promote less turbulence to enhance settling rates of suspended particles. A familiar baffle system used in water treatment is a staggered series of vertical walls that increase the tortuosity and length of the flow path through the clarifier.

TABLE 03: Classification of Density Separation

Level II	**Settling**		**Flotation**
Level III	Chemically Assisted	Unassisted	Lighter material
			Heavy Material
Level IV	Simple	Simple	
	Lamellar	Lamellar	
	Baffled	Baffled	
	HDS	HDS	

Hydrodynamic separation is typically achieved by introducing the flow tangentially into a cylindrical vessel, thus forming a vortex or swirling action. This rotary flow action tends to concentrate settleable particles that gravitate for removal or deposition within a sump. The term vortex separation, swirl separation, accelerated gravity or teacup separation, are collectively known as hydrodynamic separation (Minton, 2005). With hydrodynamic separation of wastewater, the footprint of the sedimentation basin was on average $1/8^{th}$ of a simple sedimentation basin providing similar performance (Minton, 2005).

3.2.2 Flotation

Flotation is a density separation process that relies on buoyant matter rising to the water surface. There are two general types of removal by flotation (Level III, Tab. 03; Minton, 2005):

4. material lighter than water:

   This is the basis of the design of most oil- water separators and is also used to capture floatable gross pollutants such as plastic, cigarette butts etc.; and

5. material heavier than water:

   Particles are made to float by introducing air bubbles in chemically pre-treated water. Air is applied near the bottom of the basin containing water to be treated. As the bubbles moves upward through the water, they attach with the particulate matter which causes particles to float and are separated (Crittenden, 2005).

4 NAMING CONVENTION

The naming of an individual TSC class is done using terms selected from the lower level (Level IV or V, Fig. 01) and progressing in sequential order up to top Level II e.g. single media chemically assisted inert filtration.

When water to be treated is pre-treated chemically before settling or filtration they are termed as chemically assisted settling or chemically assisted filtration respectively. When such pre-treatment is not undertaken, instead of using a term like unassisted, simply the treatment mechanism is used e.g. single inert media filtration. Tab. 04 provides a selection of individual TSC classes, together with examples of stormwater treatment devices that fall into each category.

TABLE 04: Categories of Treatment System Components and some TSC example

Categorization of TSCs	
Screening	Amiad Self Cleaning Screen, Copa Cyclone
Filtration- Unassisted	
Single Media Inert Filtration	Austin Sand Filter, Slow Sand Filter, Rapid Sand Filter
Multi-Media Inert Filtration	Dual Media, Tri-Media filter, Dual Porosity Filter
Filtration- Chemically Assisted	
Single Media Chemically Assisted Inert Filtration	Chitosan Enhanced Sand Filter (CESF)
Multi-Media Chemically Assisted Inert Filtration	Chitosan Enhanced Trench Drain Filtration System
Settling - Unassisted	
Simple Settling	Settling Tank, Settling Basin
Baffled Settling	Stormvault, Stormceptor, BaySaver
Lamellar Settling	Lamellar Plates, Tube Settler, Terre Kleen
HDS	Downstream Defender, Vortechs,
Settling – Chemically Assisted	
Simple Chemically Assisted Settling	Alum injection, Auckland Passive Injection System, Coagulation added to pond water
Baffled Chemically Assisted Settling	Suzuki High Rate Sedimentation, Microsep, SIROFLOC
Lamellar Chemically Assisted Settling	Canada NWRI Clarifier, Actiflo, DensaDeg, Delreb
HDS Chemical Assisted Settling	Korean Vortex Concentrator
Flotation	
Light Material Flotation	Kleerwater Oil water Separator, Snout Oil-Debris Separator
Heavy Material Flotation	Dissolved Air Flotation

5 CONCLUSION

A simple classification of TSCs, based on two primary treatment mechanisms and up to four sublevels is proposed in paper. TSCs with common characteristics are grouped into two categories namely density separation and size separation, located at the top Level I. density separation and size separation are further classified up to Level IV and V respectively. Classification of TSCs on the basis of treatment mechanism is not a straightforward method, as most systems have more than one treatment mechanism, which complicates the classification.

This paper focused on the TSCs suitable for urban areas for suspended solids removal suitable to generate water to a non-potable standard. This classification will assist in the screening of treatment systems. This is an initial step for the classification of treatment systems based on performance curves using particle count. Further work will investigate treatment system performance based on log reduction of particle count at various hydraulic loading rates.

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